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Handbook of weather messages, Part II

5th edition

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THE METEOROLOGICAL MAGAZINE

Vol. 97 No. 1153, August 1968

INTERNATIONAL METEOROLOGICAL ORGANIZATION PRIZE AWARDED TO SIR GRAHAM SUTTON, C.B.E., F.R.S.

The International Meteorological Organization (IMO) Prize, which is awarded annually for outstanding work in meteorology and in international collaboration, was awarded to Sir Graham Sutton (United Kingdom) by the World Meteorological Organization (WMO) Executive Committee in June 1968 at its twentieth session at the WMO Secretariat in Geneva.

The IMO Prize was established in 1955 by the WMO in honour of the former non-governmental organization which had initiated international collaboration in meteorology in 1873. The Prize consists of a gold medal, U.S. $1200, and a diploma giving the citation of the award.

For more than 30 years, Sir Graham has been accorded international recognition as a meteorologist of outstanding scientific ability. In particular, his fundamental research into the theory of atmospheric diffusion has been of far-reaching importance. His work in this field has provided a practical basis, now used in many countries, for estimating the concentration and spread of pollutants in different meteorological conditions.

A graduate of the University College of Wales and of Oxford, during the Second World War he held a number of responsible posts in research into subjects such as chemical defence, rocket ballistics, tank armaments and radar. From 1947 to 1953 he was Professor of Mathematical Physics and later Dean of the Royal College of Military Science.

As Director-General of the British Meteorological Office from 1953 until his retirement in 1965, Sir Graham played a leading part in the activities of the WMO, especially as a member of its Executive Committee. Over the years he worked constantly to further international collaboration in meteorology.

His 12-year term as Director-General of the British Meteorological Office was marked by substantial developments in that organization, especially in its research activities.

Sir Graham was elected Fellow of the Royal Society in 1949, and was knighted in 1955. President of the Royal Meteorological Society from 1953 to 1955, he was awarded the Symons Gold Medal by the Society in 1959. He was Chairman of the National Committee for Geodesy and Geophysics from 1960 to 1966.

Sir Graham's interest in and devotion to science did not come to an end with his retirement. He continues to contribute his scientific knowledge as Chairman of Britain's Natural Environment Research Council.

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FORECASTING LARGE 24-HOUR RAINFALL TOTALS IN THE DEE AND CLWYD RIVER AUTHORITY AREA FROM SEPTEMBER TO FEBRUARY

By C. A. S. LOWNDES

Introduction. An investigation is being undertaken by the Dee and Clwyd River Authority and the Water Resources Board into river regulation, and there is therefore a special interest in forecasting rainfall in the drainage area of Lake Bala and the Chester Dee. For the years 1911–66, the dates of occasions when any station in the Dee and Clwyd Area recorded at least 2 in of rain or 4 per cent of the annual mean rainfall in 24 hours were noted. Only readily available data were used, so that not all occasions were included. Rainfall amounts are given in inches and heights in feet although the units now used are millimetres and metres. Reports from Bala (Craig Nant) and Llanuwchllyn (Plas-Deon) were not used because of their doubtful accuracy. The synoptic type in the region of the British Isles was noted for each day according to the Lamb classification.[1] Of the 32 occasions, 16 occurred in the winter half of the year (October to March) and 16 in the summer half (April to September). Of the 16 days in the winter months, 15 were classed as westerly and one as southerly. None of these occasions was associated with reports of thunder or observations of atmospherics. Of the 16 days in the summer months, 11 were classed as cyclonic, 3 as westerly, one as southerly and one could not be classified. Of the 11 days classified as cyclonic, 8 were associated with reports of thunder. None of the 3 days classified as westerly was associated with reports of thunder or observations of atmospherics.

A detailed investigation was made of eight of the westerly situations and the occasions are numbered from 1 to 8 for convenience in this article. The dates and highest rainfall values were as follows :
(1) 8 February 1946, 2·05 in, (2) 26 October 1959, 2·59 in, (3) 3 December 1960, 2·92 in, (4) 2 April 1962, 3·50 in, (5) 25 September 1963, 2·12 in, (6) 12 December 1964, 5·39 in, (7) 8 December 1965, 2.58 in, (8) 17 December 1965, 4·98 in. All but one of the highest rainfall values were recorded at Afon Mynach (1200 ft), the exception being occasion (3) when 2·92 in were recorded at Bala Grammar School (540 ft) and 2·36 in at Afon Mynach. The occasions were mainly chosen from 1959 onwards because of the better surface and upper-air data available in recent years. Figure 1 shows the position of the Dee and Clwyd River Authority Area. One example of the detailed descriptions, that for occasion (2), is given below.

The situation on 26 October 1959. The rainfall for 24 hours ending 0900 GMT on 27 October at some of the recording stations in the Area was (i) Afon Mynach, 2·59 in, (ii) Bala Grammar School, 2·31 in, (iii) Alwen, 1·09 in and (iv) Alwen Dam, 1·04 in.

Figure 2 shows the surface chart for 0600 GMT on 26 October 1959 when a deepening wave-depression (992 mb) was centred west of Iceland and a slow-moving depression (980 mb) was over the Norwegian Sea. The west-north-westerly flow in the warm sector suggested that the wave-depression would move towards the north of the British Isles and by 1200 GMT (see Figure 3)

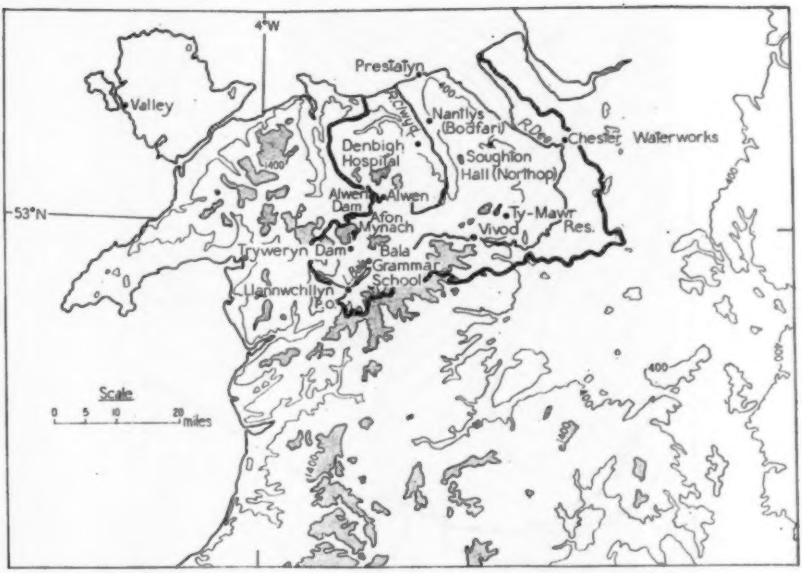

FIGURE 1—THE DEE AND CLWYD RIVER AUTHORITY AREA
The 400 ft contour is shown and areas above 1400 ft are shaded.
The boundary of the area is indicated by a thick line.

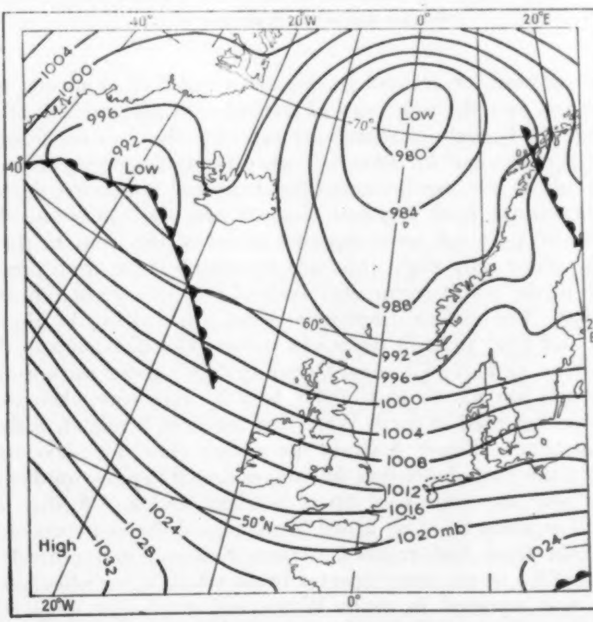

FIGURE 2—SURFACE CHART FOR 0600 GMT, 26 OCTOBER 1959
Isobars are at intervals of 4 mb.

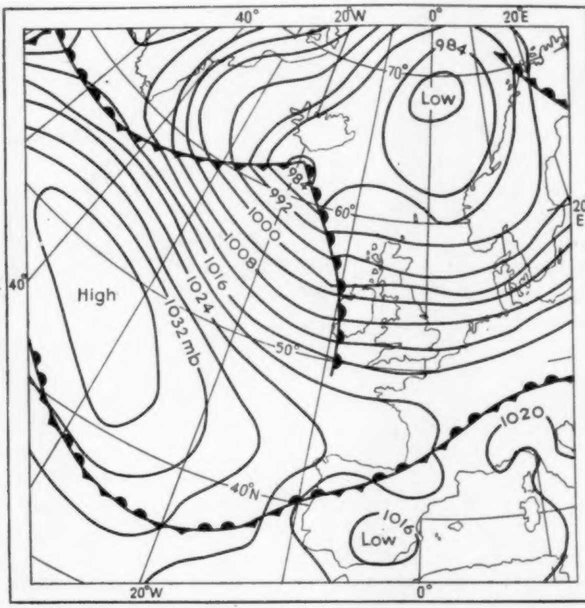

FIGURE 3—SURFACE CHART FOR 1200 GMT, 26 OCTOBER 1959
Isobars are at intervals of 4 mb.

it was centred south of Iceland having deepened further to 984 mb. The warm front was over the west coast of Ireland with pressure falls of 2 – 3 mb over Ireland. Only slight showers were reported ahead of the front. Figure 4 shows the surface chart for 1800 GMT when the wave-depression had moved south-eastwards to the north-west of Scotland and continued deepening to 972 mb. The warm front was now situated over the west coast of Britain. Pressure falls of 4 – 5 mb were reported ahead of the front in the latitude of the Area, where only slight rain was reported. There were pressure falls of 6 – 8 mb in the warm sector over Ireland but only slight rain or drizzle was occurring. The surface geostrophic wind was 240° 50 kt ahead of the warm front and 270° 50 kt in the warm sector. The dew-point in the warm sector was about 51°F (11°C), some 6 degF (3 degC) above the normal.[2] The warm front had just moved east of the Area by 2100 GMT when continuous heavy rain was reported in north Wales and southern Scotland, both situated in the warm sector. Figure 5 shows the surface chart for 0000 GMT on 27 October when the wave-depression, having continued to move south-eastwards, was centred over the north-west tip of Scotland and had further deepened to 960 mb. The warm front lay across Scotland and the east coast of England whilst the cold front had reached western Scotland and central Ireland. Pressure falls of 8 – 10 mb were reported in the warm sector where continuous heavy rain was reported in south Wales and north-west England. Continuous heavy rain was still reported in north-west England at 0300 GMT. By 0600 GMT the wave-depression had deepened to 956 mb and had moved

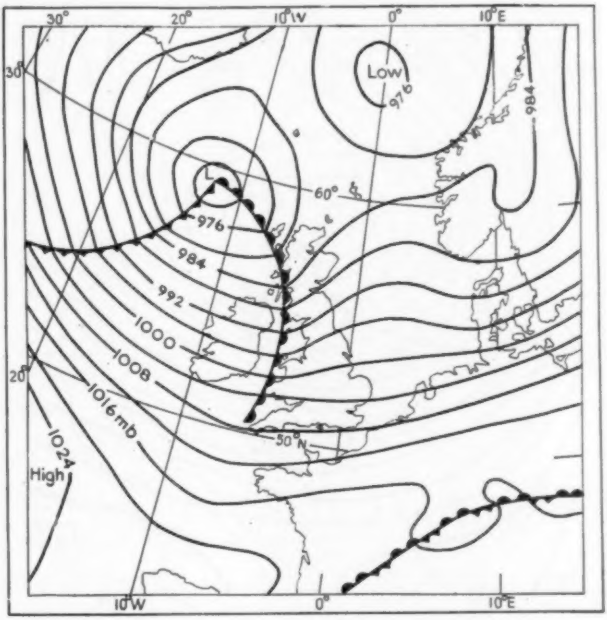

FIGURE 4—SURFACE CHART FOR 1800 GMT, 26 OCTOBER 1959
Isobars are at intervals of 4 mb.

across northern Scotland to the North Sea. Occlusion had not yet begun. The cold front had cleared the Area and was situated over south-east England with some continuous slight and moderate rain on its western side. By 0900 GMT, a showery type of weather had reached Wales. The heavy rainfall over Wales occurred between 2100 GMT 26 October and 0900 GMT 27 October and appeared to be mainly associated with the warm sector.

The 500 mb chart for 0000 GMT, 27 October (Figure 6) shows a trough just west of the British Isles. Winds of over 70 kt were reported at Aldergrove (82 kt) and at Ocean Weather Station J (104 kt). This suggested the existence of two jet streams, neither of which fitted the Benwell criteria[3] for heavy rain over the Area. However, the jet stream associated with 82 kt at Aldergrove was probably only slightly too far north and it was considered to be a borderline occasion.

The tracks of the depressions. Figure 7 shows the tracks of the depressions, wave-depressions and waves for the eight occasions listed in the introduction. The reference numbers of the occasions are used for numbering the tracks. The depressions approached the British Isles from the north-west, west and west-south-west. The majority moved eastwards across northern England, Scotland, or to the north of Scotland. Only one turned and continued northwards towards the Norwegian Sea before reaching the British Isles. On occasions (3) and (4) the rain was partly associated with an

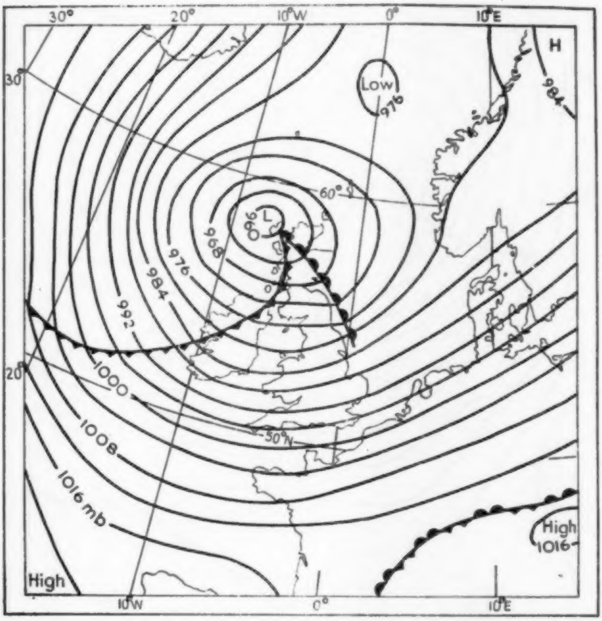

FIGURE 5—SURFACE CHART FOR 0000 GMT, 27 OCTOBER 1959

Isobars are at intervals of 4 mb.

occluding depression (3a), (4a), and partly with waves on the cold front (3b), (4b). On occasion (7) the rain was partly associated with one occluding depression (7a) and partly with another (7b).

A summary of the eight occasions. The eight occasions showed some similarities as follows :

(i) The rainfall was associated on all occasions with a warm sector which moved eastwards across the Area. On occasion (3b) the tip of a wave moved eastwards just north of the Area and on occasion (4b) the tip of a wave moved north-eastwards from southern Ireland across southern Scotland to the North Sea. On occasions (1) and (6) the tip of a wave-depression crossed the British Isles just north of the Area and on occasion (2) one crossed northern Scotland. There was no occlusion. On occasions (4), (5) and (8) the point of occlusion of a depression moved eastwards across the extreme north of Scotland and on occasion (3a) one moved south-eastwards across central Scotland. On occasion (7a) the point of occlusion moved south-eastwards across southern Scotland and on occasion (7b) another moved eastwards across central Scotland.

(ii) On all occasions except (4) and (7a) the associated depression or wave continued to deepen throughout the actual day. On occasion (4) the depression deepened until 0000 GMT on the actual day, then showed no change

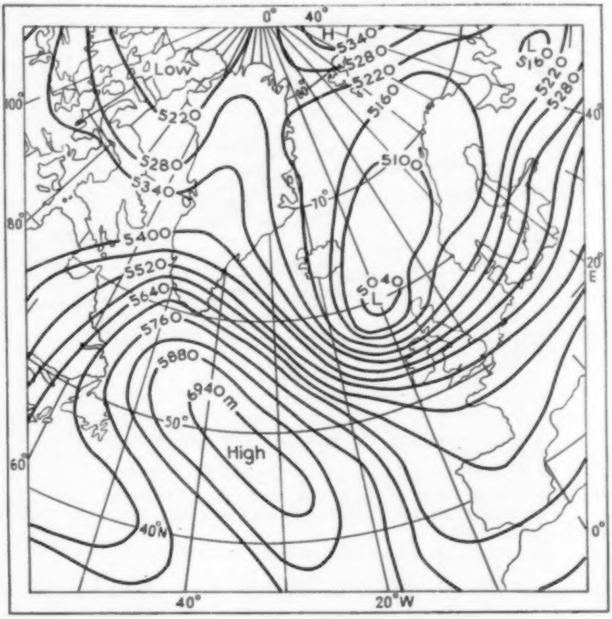

FIGURE 6—500 MB CHART FOR 0000 GMT, 27 OCTOBER 1959

Isopleths are at intervals of 60 m.

Note: the 6940 m isopleth should be labelled 5940 m.

during the next 24 hours. On occasion (7a) the depression deepened until 0600 GMT on the actual day, then showed no change until 1800 GMT.

(iii) With the exception of occasion (7a) the lowest pressure at the centre of the associated depression or at the wave-tip during the rainfall day ranged from 956 mb to 988 mb.

(iv) On each occasion, there was a maximum 3-hour surface pressure fall of between 3 mb and 7 mb ahead of the warm front and between 3 mb and 8 mb in the warm sector.

(v) With the exception of occasions (4) and (7a) the surface dew-point in the warm air ranged from 6 to 11 deg F (3 to 6 deg C)above the normal.[2] On occasion (4) the dew-point was about normal and on occasion (7a) it was 4 degF (2 degC) above the normal.[2]

(vi) With the exception of occasions (1) and (2) when the surface geostrophic wind ahead of the warm front was light, the winds were rather strong, ranging from 30 to 70 kt ahead of the warm front and from 40 to 70 kt in the warm sector. The geostrophic wind direction ranged from 220° to 240° ahead of the warm front and from 230° to 280° in the warm sector.

The Benwell criteria[3] indicated heavy rainfall over the Area on occasions (4) and (7), i.e. on two days out of eight. Three other days were considered to be borderline occasions. The requirement of the criteria that the left exit

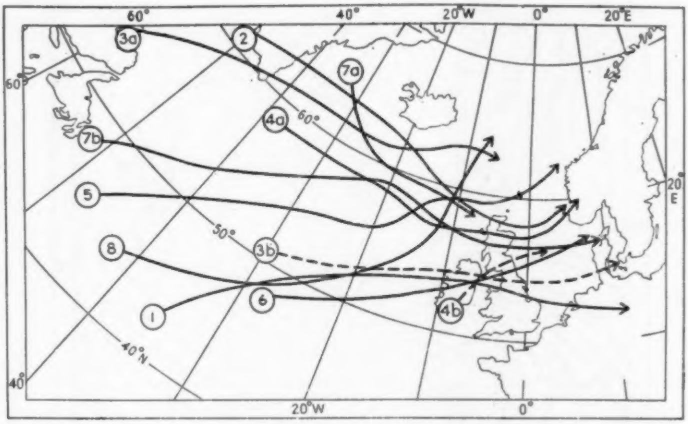

FIGURE 7—TRACKS OF THE DEPRESSIONS AND WAVES

———— Track of depression. – – – – Track of wave.

(1) 8 February 1946, (2) 26 October 1959, (3a) and (3b) 3 December 1960, (4a) and (4b) 2 April 1962, (5) 25 September 1963, (6) 12 December 1964, (7a) and (7b) 8 December 1965, (8) 17 December 1965.

of the jet stream at 500 mb should be over the Area was the subject of rather critical decisions; on nearly all the heavy rain days the Area was associated with a jet-stream exit but with the right-hand side rather than the left. It is possible that the relative failure of the Benwell criteria on the occasions studied in this investigation was due to the rainfall being mainly orographic in origin and the dynamical effect being small. Figure 8 shows the average daily rainfall for the eight occasions plotted against the height above sea level of a number of rainfall stations in the Area. The stations used, together with their heights above sea level, were as follows :
(i) Prestatyn 10 ft, (ii) Chester Waterworks 90 ft, (iii) Nantlys (Bodfari) 180 ft, (iv) Denbigh Hospital 310 ft, (v) Soughton Hall (Northop) 420 ft, (vi) Bala Grammar School 540 ft, (vii) Vivod 640 ft, (viii) Ty-Mawr Reservoir 810 ft, (ix) Alwen 1100 ft, (x) Alwen Dam 1190 ft, (xi) Afon Mynach 1200 ft. Up to 400 ft, the rainfall was roughly constant at about 0·5 in. Above 400 ft, the rainfall was higher but showed large variations, no doubt associated with the difference in exposure of the stations. The rainfall ranged from 0·79 in at 810 ft to 3·18 in at 1200 ft. It is clear that the orographic effect was important, in particular at Bala Grammar School (540 ft) and Afon Mynach (1200 ft), but the average rainfall at Valley (near Holyhead) (a station situated at 30 ft above sea level on the west coast of Anglesey and relatively free from orographic effects with westerly winds) was 0·5 in, indicating a substantial dynamical contribution to the rainfall.

Criteria for indicating 24-hour rainfall totals of 2 in or more in the Dee and Clwyd Area in the months September to February

(i) A deepening partly occluded depression, wave-depression or wave moves towards the longitude of the British Isles, keeping south of Iceland, from directions between north-west and west-south-west.

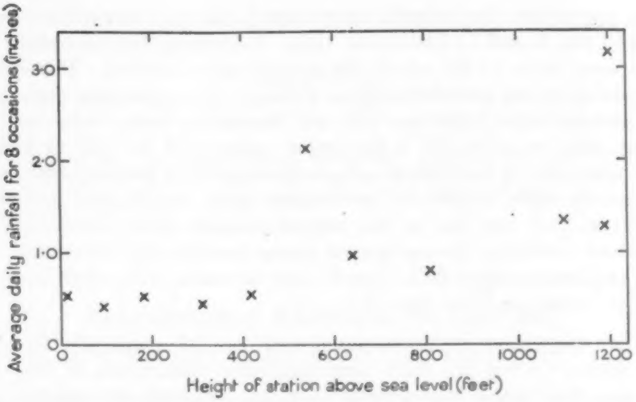

FIGURE 8—THE RELATION BETWEEN HEIGHT ABOVE SEA LEVEL AND THE AVERAGE DAILY RAINFALL FOR EIGHT OCCASIONS AT ELEVEN RAINFALL STATIONS IN THE DEE AND CLWYD AREA

(ii) The point of occlusion or the wave-tip moves eastwards across or north of the British Isles, to the north of Wales and south of the Faeroes, i.e. a warm sector crosses the Area.

(iii) The depression or wave continues to deepen until midnight of the 'rainfall day' i.e. 0900 GMT (d) to 0900 GMT ($d+1$).

(iv) The central pressure or the pressure at the wave-tip falls to 988 mb or less during the 'rainfall day'.

(v) There are 3-hour pressure falls of 3 mb or more ahead of the warm front and in the warm sector in the vicinity of the Area.

(vi) The surface dew-point in the warm sector is 6 degF (3 degC) above the normal[2] in the vicinity of the Area.

(vii) The surface geostrophic wind speed in the warm sector is 40 kt or more and the direction is from 230° to 280° inclusive in the vicinity of the Area.

The above criteria were satisfied on all occasions except (4), which occurred in April, and (7a). Occasions (4) and (7) were the only ones which satisfied the Benwell criteria[3] for heavy rain over the Area.

It is interesting to note that Holgate, in some unpublished work on forecasting prolonged heavy rainfall with a minimum of 6 hours at 0·22 inches per hour in the Lake District and North Wales, obtained rather similar criteria. In particular, he found such rainfall to be associated with the occluding warm sector of a deepening depression.

A test of the criteria on independent data. A test of the criteria was carried out for days classified by Lamb[1] as westerly in the months September to March for the five years 1962–66. These periods included four of the eight

occasions on which the criteria were based, i.e. 25 September 1963, 12 December 1964, 8 and 17 December 1965. Excluding these occasions, of the 233 days there were 11 on which the criteria were satisfied. The dates and highest rainfall values recorded were as follows: (i) 20 January 1962, 0·98 in, (ii) 4 February 1962, 1.82 in, (iii) 21 November 1963, 1·65 in, (iv) 13 November 1964, 1·43 in, (v) 8 December 1964, 2·58 in, (vi) 11 December 1964, 2·07 in, (vii) 29 December 1964, 1·89 in, (viii) 9 January 1965, 2·43 in, (ix) 10 January 1965, 1.93 in, (x) 31 October 1965, 1·99 in, (xi) 29 November 1966, 1·60 in. All but two of the highest rainfall values were recorded at Afon Mynach (1200 ft), the exceptions being occasion (iii) when 1.65 in was recorded at Llanuwchllyn P.O. (570 ft) and occasion (viii) when 2·43 in was recorded at Tryweryn Dam (900 ft).

Of the 11 days, four were associated with rainfall totals of 2 in or more and five with 1·5 – 1·9 in. Two were associated with totals of 1·0 – 1·5 in. For the 222 days when the criteria were not satisfied, the rainfall ranged from nil to 1·85 in. A rainfall total of 1·5 in or more was recorded on only six occasions, on two of which the rainfall was mainly associated with a quasi-stationary cold front and on one it was associated with a wave on a cold front. If the four occasions on which the criteria were partially based were included, the criteria would have indicated all the eight occasions with totals of 2 in or more which actually occurred and also five occasions with 1·5 to 1·9 in and two occasions with 1·0 to 1·5 in. There were no occasions with totals of 2 in or more for the month of March in the five years and the only occasion with more than 1.5 in was not indicated by the criteria. There is therefore no evidence that the criteria would be of use in March.

The Benwell rules[3] indicated heavy rain over the Area on occasions (i), (viii), (x) and (xi) but the requirement that the left exit of the jet stream at 500 mb should be over the Area was the subject of highly critical decisions. Again, on nearly all occasions, the Area tended to be associated with the right exit rather than the left.

The result of reducing the number of criteria. It is obvious that the seven criteria are highly correlated and it might therefore be possible to reduce their number without seriously affecting their success as rainfall indicators. It was found that the number could be reduced to six, by excluding either criterion (iv) or (vii), without affecting the indications. Any other reduction of one or more criteria resulted in the addition of some days with low rainfall to the indications. This is not surprising since the various values quoted in the criteria represent threshold values which were always reached and usually passed; elimination of any of them is therefore likely to admit occurrences below the required intensity.

Conclusions. Daily rainfall totals of 2 in or more in the Dee and Clwyd River Authority Area were nearly all associated in the winter half of the year with westerly types, in particular with the warm sector of deepening depressions or waves. Seven criteria for indicating totals of 2 in or more were obtained for the months September to February. In a test on independent data, all occasions with totals of 2 in or more were indicated, together with a number of occasions with 1·0 to 1·9 in. The number of criteria could not

be reduced by more than one without the addition of some days with low rainfall to the indications.

REFERENCES

1. LAMB, H. H.; Types and spells of weather around the year in the British Isles: Annual trends, seasonal structure of the year, singularities. *Q. Jnl R. met. Soc., London*, **76**, 1950, p. 393.
2. Washington, D.C., U.S. Department of Commerce. Climatological and Oceanographic Atlas for Mariners, Vol. 1, North Atlantic Ocean. Washington, D.C., 1959.
3. BENWELL, G. R. R.; The jet stream at 500 mb as a predictor of heavy rain. *Met. Mag., London*, **96**, 1967, p. 4.

551.509.311:551.577.37(425)

REMARKABLE RAINFALL IN OXFORD

By D. McFARLANE, M.B.E., and C. G. SMITH, M.A.*

Summary. Intense rainfall occurred in the Oxford area during a thunderstorm on the evening of 13 July 1967. The associated synoptic situation and forecasting problems involved are described. Convergent flow at medium levels is suggested as a possible explanation of the location and intensity of the storms. A detailed examination of the distribution of rainfall and resulting flooding and damage are described. Drainage in urban areas is often inadequate for rainfall of this intensity because of the high proportion of impermeable surface and the variability of the run-off load. There is an apparent increase in recent years of the frequency of falls of rain exceeding two inches in a day in the Oxford area.

Synoptic situation. Pressure gradients had been slack for several days over a wide area of western Europe, extending from Spain across France to England. An anticyclone centred near the English Channel on 10 July had gradually weakened and by 13 July a shallow depression covered the area. At 700 mb and 500 mb a shallow trough in the eastern Atlantic on 10 July gradually became organized as a closed circulation west of Ireland during the period, producing a light south to south-west flow over the area.

The weather was fine and warm over Spain, France and much of England on 10 and 11 July apart from an outbreak of thunderstorms over north-east Spain on the evening of 11 July. Storms were resumed in this latter area in the afternoon and evening of 12 July, and by the same evening two new areas of storms had been identified — one over Ireland and a more extensive area located by SFERIC reports in the South-western Approaches.

Forecasting problems. The forecasting problem for southern England and the Midlands appeared, at this point, to be more concerned with the advection of storms from the south than with development *in situ*. The midnight ascents from Camborne and Crawley (Figure 1) seemed too dry for more than a few isolated storms to be released by a combination of day-time heating and orographic lifting. On the other hand the Lowndes[1] criteria for rain in south-east England were satisfied, and the ascents from Trappes and Uccle were extremely unstable. The area of storms noted earlier over north-east Spain seemed favourably placed in relation to winds at medium levels to be carried northwards over western France but, in fact, by midnight there appeared to be only isolated storms in the same area. Early forecasts for 13 July were thus framed in a very general way with the possibility of storms in almost any part of England in mind.

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During the morning, storms did reappear moving steadily northwards over western France and the Bay of Biscay and forecasts began to be more confident and specific as to storms spreading across England from the south during the night. In particular, storms were forecast in the Abingdon area for about 2100 GMT. Timing was based on extrapolation of past movement and this was in good agreement with the flow at medium levels. However, after reaching the north coast of Brittany in the early afternoon this area of storms appeared to die out very quickly and the only further evidence of thundery activity during that afternoon consisted of two isolated SFERIC reports at 1400 GMT in the English Channel north-west of the Channel Islands. Hence, with nothing menacing upwind and little or no sign of any development over England, forecasters were playing down the thunderstorm risk by late afternoon.

Thunderstorms developed that evening with dramatic suddenness on a line from Bristol to Bath and thence along the northern edge of the Berkshire Downs to a point just east of Didcot. The initial outbreak seems to have occurred between Devizes and Bristol at about 1745 GMT or a little earlier and storms were seen to the south of Abingdon at about 1835 GMT. Study of all

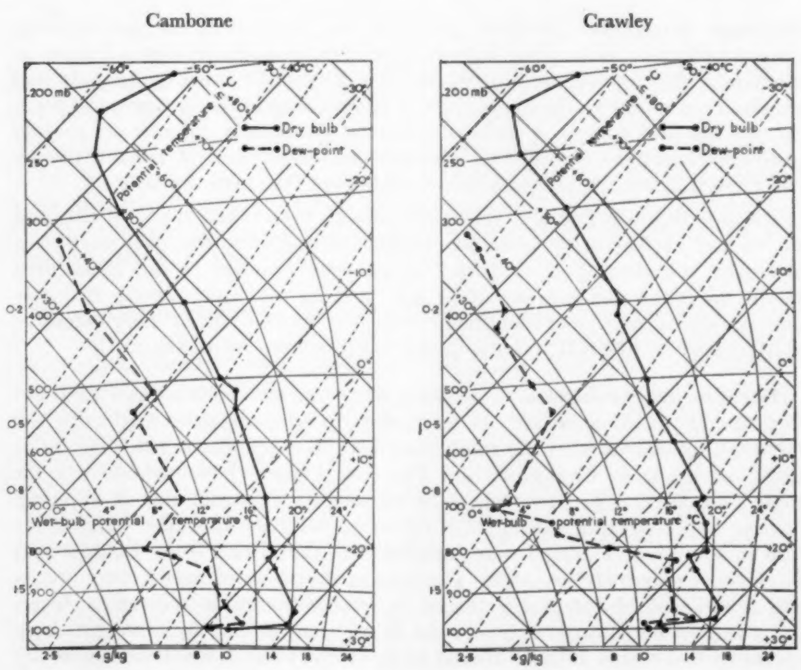

FIGURE 1—UPPER AIR SOUNDINGS FROM CAMBORNE AND CRAWLEY AT 0000 GMT, 13 JULY 1967

———— Dry bulb - - - - Dew-point

available observations in the area affected revealed a remarkable similarity in the sequence of events prior to the storms. In every case there were no more than two oktas of medium cloud, mostly castellanus, with cirrus above, up to an hour before the storms began. In no case was cumulonimbus observed before the storms which were, in fact, preceded by a very rapid increase to five to eight oktas of altocumulus castellanus. Observations to the south of the line on which the initial outbreak occurred were studied for evidence of the passage of any organized area of instability. No such evidence was found. For example, throughout the period from 1600 GMT to midnight, Boscombe Down had less than three oktas of medium cloud, and cumulonimbus and lightning were not observed until 2000 GMT and then to the north and north-east.

It seems reasonable to assume that instability was released at medium levels and that the storms were not advected from the south-south-west; also the complete lack of reports of cumulonimbus before the storms shows clearly that instability was not released at low levels. The flow at 700 mb and 500 mb apppears to provide a more acceptable solution to the occurrence. Charts for these levels on 13 and 14 July are shown in Figures 2 and 3. During the day the cyclonic circulation to the west of Ireland at these levels moved slowly east thus increasing the south-south-westerly flow over the South-western Approaches, south-west England and Brittany. This resulted in the acceleration north-north-eastwards of very moist air whose origin was over Spain. At the same time the flow became very markedly convergent in the area bounded in the south-west by a line from Brest to Camborne and in the north-east by a line from Crawley to Aughton. This convergence reached a maximum during the evening as can be seen from the chart for 1800 GMT. The location of the first outbreaks just to the north of the Mendips and the Berkshire Downs suggests that orographic lifting provided the trigger but that convergence and high moisture-content were the principal causes. It is also significant that the areas of thundery activity in the South-western Approaches and over Ireland at 0000 GMT on 13 July appear to be associated with areas of convergence at medium levels.

Nature and distribution of rainfall in the Oxford district. Rainfall n the Oxford district during this storm was remarkable for its intensity and for its limited distribution. Figure 4 shows the amount and distribution of rain over the 24-hour period commencing at 0900 GMT, 13 July, as measured at 148 rainfall stations in north Berkshire, Oxfordshire and adjacent portions of Gloucestershire, Wiltshire and Buckinghamshire. Of these stations 141 are recognized by the Meteorological Office. Another 7 are maintained less regularly by schools and private individuals, but have records that are considered acceptable for that day.

The southern limit of the area within which rain fell coincides very closely with the escarpment of the Berkshire Downs and Chilterns from Swindon through Wantage, Wallingford, and Princes Risborough to Aylesbury. Some rain occurred over the whole area to the north of this, as far as a line from Tewkesbury through Banbury to Leighton Buzzard. However, in only two areas was the fall substantial, amounting to over one inch: a narrow belt in the central Cotswolds, extending some 10 miles north-eastwards from

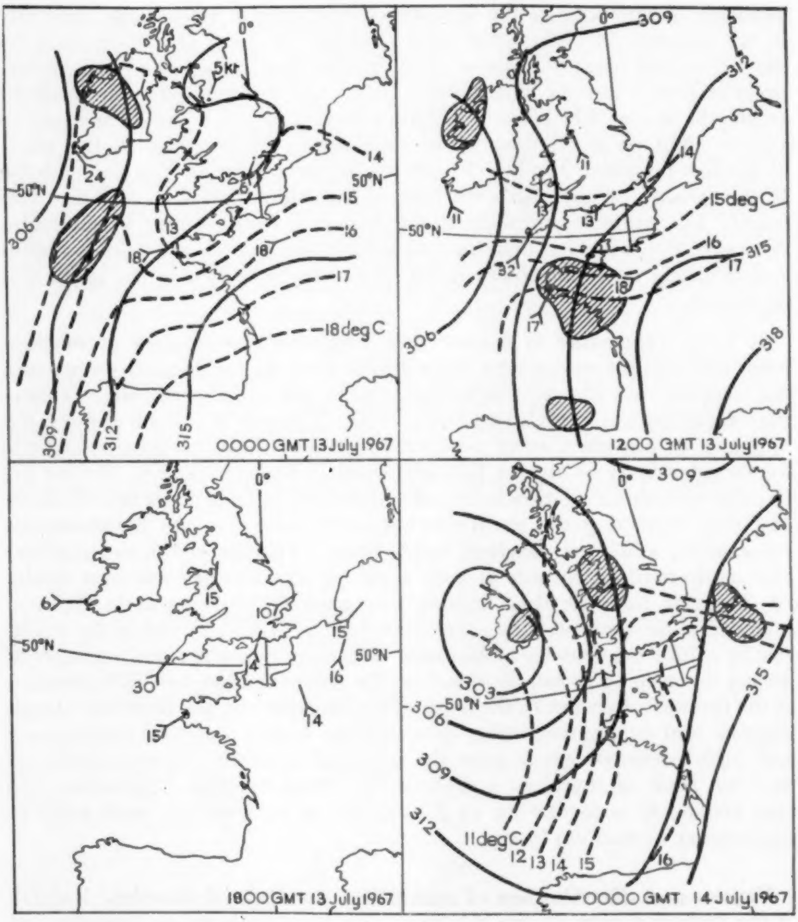

FIGURE 2—CONTOUR CHARTS FOR 700 MB LEVEL, 13–14 JULY 1967

– – – – Isopleths of 700 mb wet-bulb potential temperature in degrees Celsius.

———— Contours at intervals of 3 decametres. Wind direction is shown by an arrow shaft and the speed in knots is given at its tail. Areas of thunderstorms are shaded.

Cirencester towards Burford, and in a rather larger area extending north-north-eastwards from Didcot and Abingdon to a point some 7 miles north-east of Oxford. No detailed investigation has been made in the first of these areas. The eastern suburbs of Oxford are in the centre of the second area where the rainfall was particularly heavy. Two rain-gauges at Littlemore and Headington recorded 2·88 and 2·64 in respectively. Neither of the gauges provided an autographic record but in both places the observers were alerted by the intensity of the rain and hail, and by the spectacular thunder and lightning

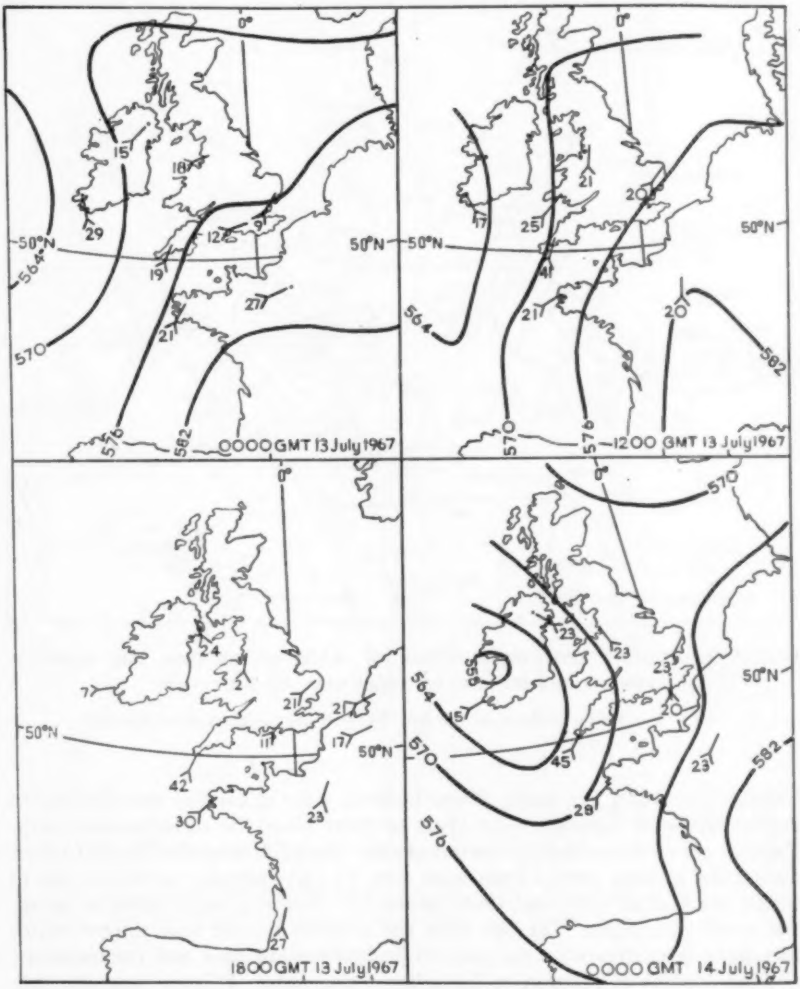

FIGURE 3—CONTOUR CHARTS FOR 500 MB LEVEL, 13–14 JULY 1967

——— Contours at intervals of 6 decametres. Winds are indicated as in Figure 2.

preceding and during the fall. Their evidence, and that of other observers in the district, including one of the authors, confirms that this fall occurred during a period of between 60 and 70 minutes.

The heaviest rain and hail fell in the Cowley district of Oxford. Here flooding of houses, roads and the factories of the British Motor Corporation (B.M.C.) and Pressed Steel Fisher Company was the worst in memory. One new housing estate, Blackbird Leys, suffered severely from flooding; in some

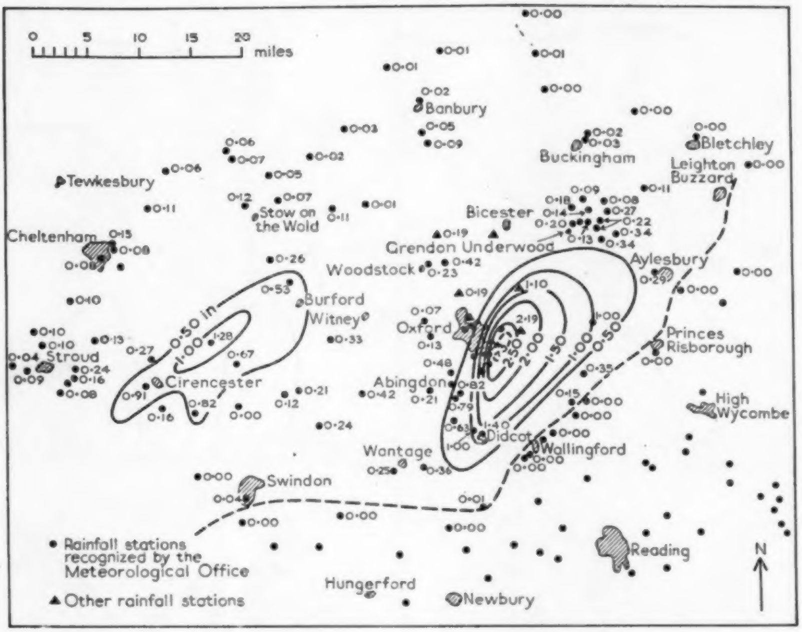

FIGURE 4—AMOUNT AND DISTRIBUTION OF RAINFALL DURING THE 24-HOUR PERIOD COMMENCING AT 0900 GMT, 13 JULY 1967

- - - - Southern limits of rainfall. Isohyets are at intervals of 0·50 in.

houses water was 3 feet deep. Other built-up areas of Cowley were flooded to depths unknown during the 50 years or more since the suburbs were built. Figure 5 shows the probable amount of rain which fell over the City of Oxford during the 24-hour period from 0900 GMT, 13 July, together with the sites to which the Oxford City and Oxfordshire Fire Brigades were called to pump out water that night. On this scale the isohyets can be only approximate; they have been drawn on the basis of limited rainfall data and the incidence of local flooding in relation to the urban topography. It is not unreasonable to conclude that around the Cowley car factories and the Blackbird Leys Estate over 3 in of rain fell in just over an hour. One of the authors was visiting the Cowley Divisional Police Station during the storm and witnessed cars attempting to climb the short hill outside the station being forced to a standstill and, in two cases, washed backwards by a torrent of water at least 6 in deep running down a road which resembled a river in spate. Double-decker buses, slowly climbing the hill, created a bow wave similar to that of a barge. The *Oxford Mail* of 14 July gave a full account of the flooding resulting from the storm and of motorists stranded in floods on roads which were transformed into rivers. Car production at the B.M.C. factory at Cowley was brought to a halt by extensive flooding of the works and night-shift workers were sent home. Damage arising from the flooding of inspection

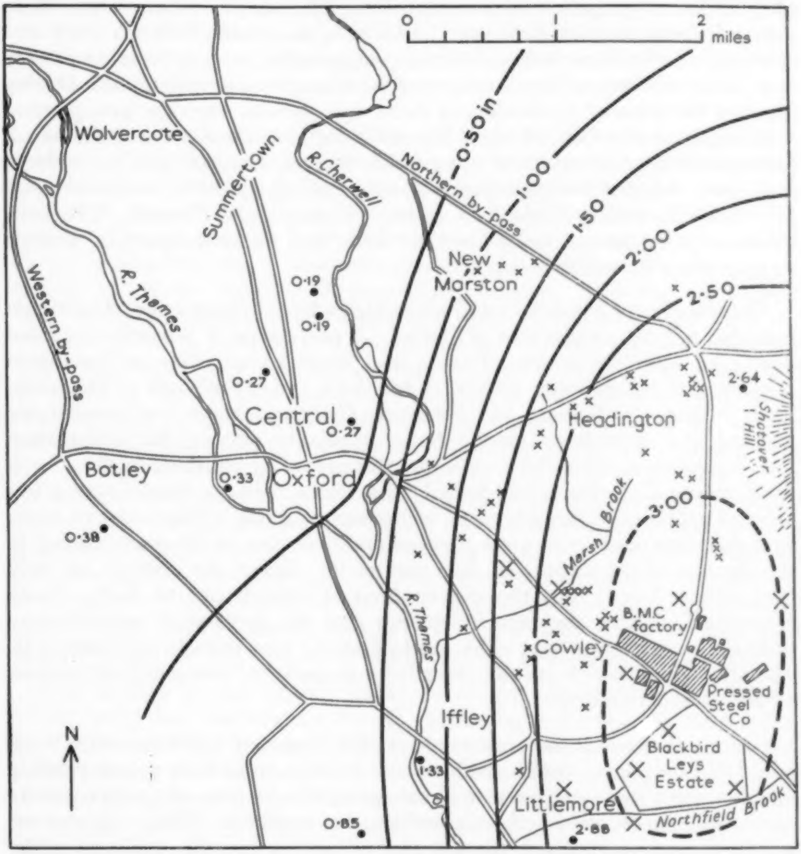

FIGURE 5—AMOUNT AND DISTRIBUTION OF RAINFALL OVER THE CITY OF OXFORD DURING THE 24-HOUR PERIOD COMMENCING AT 0900 GMT, 13 JULY 1967

• Rain-gauge sites. x Individual flood calls. ╳ Flooding widespread.
Isohyets are at intervals of 0·50 in.

pits and electric cables was extensive at this factory. In a nearby car park, used by a car delivery firm, 400 cars were extensively damaged by flooding; in some parts of the park, water was 3 ft deep. That part of Oxford lying north and west of the Thames and Cherwell received little rain compared with the eastern suburbs of the city. The presence of several rain-gauges in west Oxford and to the west of the city makes it possible to draw isohyets there more confidently. Figure 5 shows that rainfall increased from 0·27 in at the Radcliffe Meteorological Station to 2·88 in over a distance of 3 miles. From personal observations during the storm, and from the extent of the flooding, it appears that there was a very sharp western edge to the belt of heavy

rain. The autographic record of the Radcliffe Station indicates that there rain fell from 2015 to 2115 GMT. The rain was heavy between 2025 and 2100 GMT. Other observations in the city suggest that the heavy rain at Cowley and Littlemore began about 2025 and lasted until about 2130 GMT. During the first half-hour of the downpour there were periods when the precipitation was largely in the form of hail. Reports refer to hailstones the size of small glass marbles, which made a great noise on cars, windows and corrugated-iron roofs. Some of the street flooding was probably caused by, or accentuated by, drains becoming blocked by masses of congealed hailstones. The hailstones were not exceptionally large for there were no local reports of damage to glasshouses by heavy hail.

The belt of very heavy rain and hail which affected Cowley and Headington extended at least 3 miles east of Oxford. A rain-gauge at Wheatley recorded over 2 in, while the measured catch in a metal wheelbarrow at Garsington suggests that rather more than 2 in fell there. In the villages of Horspath, Little Milton, the Baldons and Nuneham Courtenay there was considerable flooding and damage to crops. A fire appliance sent by the Oxfordshire Fire Service from Wheatley to attend a fire caused by lightning in the church at Nuneham Courtenay, was halted on a minor road by flood water 4 feet deep. Reports from farmers speak of the storm having a sharp eastern edge, with extensive damage in some parishes and little rain in the next. Owing to the absence of rain-gauges in that part of the district the isohyets are only approximate there; but the eastern limit of rainfall can be fairly closely determined. There are some indications that the decrease of rainfall away from the storm centre was more gradual to the east than to the west of it. The area within which rainfall exceeded 2 in probably amounted to between 20 and 30 square miles.

Figure 4 shows that the area where rainfall exceeded 1 inch extended from near Didcot, about 10 miles south-west of Cowley, to at least 7, and possibly 12 miles north-east. A cluster of 14 rain-gauges in an area of 15 square miles near Grendon Underwood, maintained in connexion with experiments by the Hydraulics Research Station at Wallingford, provides evidence of the rapid decrease in the amount of rain along this south-west–north-east axis. The central axis of the rain belt may have lain to the south-east of this cluster of rain-gauges, but there is clear evidence that it was north-west of Aylesbury. At Bletchley, 10 to 12 miles further to the north-east, there was no rain. The area that received over 0·5 in of rain was about 25 miles from south-west to north-east, and about 10 miles wide. The area of heavy rain between Cirencester and Burford was also elongated along a south-west to north-east axis. Here the area receiving over 0·5 in was approximately 25 miles long by 6 miles wide. It is possible that there were other cells of heavy rain between this storm and that in the Oxford area since two stations, one to the west and one to the north of Oxford, received 0·42 in. However, the network of rain-gauges is sufficiently close to detect any substantial areas of rainfall exceeding 0·5 in. Thunder and lightning were widely reported that evening over the whole area shown on Figure 4. These reports confirm the local evidence from the Oxford area that the storms were moving from south-west to north-east. Rainfall commenced at Abingdon aerodrome at 1930 GMT, at Oxford at 2015 GMT and at Grendon Underwood at 2200 GMT. Thunder and

lightning were first noted at Compton, Berkshire, at 1815 GMT, at Abingdon at 1835 GMT, at Oxford at 1930 GMT and near Aylesbury at 2200 GMT. The storm appeared to be directly overhead at Abingdon aerodrome at 2010 GMT and at Cowley between 2045 and 2115 GMT.

Rainfall intensity and flooding. This thunderstorm provides further evidence of the very heavy rainfall that can occur over a small area during thundery conditions. A similar local thunderstorm struck central and north Oxford in the early hours of 7 September 1951, and has been described elsewhere.[2] The shape of the belt of heavy rain during the 1951 storm was not so well established, but it was extremely narrow. On that occasion 3·34 in of rain fell at the Radcliffe Meteorological Station. This was the greatest daily fall ever recorded there. Records of daily rainfall at the Radcliffe site go back to 1815, and the autographic rainfall records are available since 1881. During the period of heaviest rain in 1951, 2·62 in fell in 1 hour and 26 minutes. A five-inch rain-gauge situated a few hundred yards away recorded 3·50 in, but 2 miles to the north and south of this site the fall was less than half this amount. Another heavy fall occurred in the Oxford district on the night of 22/23 June 1960 during which 3·20 in of rain fell at the Radcliffe Meteorological Station and 3·44 in at the station a few hundred yards away. On this occasion the rainfall was spread over a period of 3 hours and 40 minutes. That night several stations in north Oxfordshire recorded falls of over 3 inches during periods which brought the fall into the category 'very rare'.[3] The intensity of the falls at Littlemore and Headington on 13 July 1967 come within the category 'very rare' and in rate-per-hour they slightly exceed the 1951 fall at the Radcliffe site. (Ed. note: see p. 245).

The flooding in east Oxford on 13 July 1967 was probably accentuated by the heavy hail blocking the drains. According to a report on the flooding by the Oxford City Engineer,[4] there was some blocking of street drains and open drainage culverts by rubbish and by soil eroded from gardens. Urban storm-drains are normally designed to Government-approved standards to cope with rainfall intensities of between 1 and 3 in/h depending on the size of the area. However, this assumes that the rainfall is evenly distributed over the hour and that drains are unblocked and undamaged. Flooding will inevitably result if neither of these conditions is met. There is abundant evidence from records of thunderstorms in Britain that over brief periods the rainfall intensity may exceed 3 in/h. For instance, during a thunderstorm at midday in Oxford in 1957, 1·08 in fell in 20 minutes, but 0·81 of this amount fell in 10 minutes, an hourly rate of 4.86 in. *British Rainfall*[5] lists 16 known occasions of 'very rare' falls between 1870 and 1956, where the intensity of rainfall has exceeded 4 in/h, averaged over the whole period, for falls exceeding 2 in; also listed are 7 occasions with an average intensity of over 6 in/h during falls exceeding 1 inch. Owing to the limited areal extent and duration of such heavy falls there are probably many equally intense falls which go unrecorded. Such heavy falls are more likely to produce immediate surface flooding in built-up areas where large areas of impermeable surfaces (roofs, streets, car parks, etc.) exist. Since urban topography varies considerably not only in terms of slope, but in the relative proportions of permeable and impermeable surfaces, the actual run-off load may vary considerably within a city, so that standards such as 3 in/h may well be too low in some areas.

When a small natural drainage channel or brook with a catchment area in open country flows through a suburban area, it may overflow during heavy rainstorms and add further amounts of water to the immediate local run-off which has to find an outlet through street drains and sewers. The overflow of two local brooks, the Northfield and Marsh Brooks with catchment areas around Shotover Hill in the belt of heavy rain, was a factor in the flooding at Cowley on 13 July.

These points concerning run-off load to drains have been mentioned here since there has been considerable criticism of the Oxford City Council and its officials, by local residents of the areas worst affected by the flooding of 13 July, on the grounds that the drainage at the Blackbird Leys Estate was inadequate or badly maintained. These charges have been answered by the City Engineer in a report already referred to[4] and it is not intended to go into this matter here.

Frequency of heavy falls of rain in Oxford. Investigation of this storm and other recent heavy falls at Oxford suggests that in recent years the frequency of heavy falls of rain in short periods may have increased. Since 1860 the Radcliffe Meteorological Station has recorded only eight occasions when more than 2 in of rain has fallen in one day. Four of these occasions have been since 1950; in September 1951, August 1957, June 1960 and August 1962. On three of these occasions the greater part of the fall occurred during a thunderstorm and in a short period. This list does not include the recent Cowley storm since this did not produce much rain at the Radcliffe site. It was certainly heavier than any storm at Cowley since 1950. Prior to 1951, of the four occasions when 2 in of rain fell in one day, only one was associated with thunderstorm rain. Table I lists by decades since 1860 the number of falls exceeding 1 in/day and 2 in/day at the Radcliffe site and distinguishes thunderstorm days from the total number. Thunderstorm days are defined as days when the rain is associated with thunder and lightning in the observer's weather diary. The frequency of falls of over 1 in/day shows a variation that is probably not significant. The recent increases in the frequency of falls of over 2 in might be explained by 'random distribution' over a relatively short period, but there is some evidence of this trend in other parts of the country.[5,6] (Ed. note: see p. 245).

Conclusions. This situation illustrated the extreme difficulties often met in forecasting summer thunderstorms. The various instability indices which have been devised are based on the instability between the surface and 700 mb and are thus not applicable to release at medium levels. Even if the convergence and increasing moisture aloft had been foreseen, it would have been reasonable to have forecast storms over much of south-west and south-east England, both of which areas escaped the storms. The situation presented problems similar to those of forecasting thunderstorms in the convergence zones near the equator, and suggests that even given a close network of upper air stations in those areas, the chances of accurately forecasting the timing and location of areas of storms would remain small.

It would seem inevitable that occasional storms of the exceptional intensity of that of 13 July at Oxford should cause flooding in cities unless intensities

TABLE I—HEAVY FALLS OF RAIN IN ONE DAY AT OXFORD

Decade	Number of daily falls of over 1 in	Number of daily falls exceeding 2 in	Number of such days when some of the rain was associated with thunder
1861 – 1870	8	1	nil
1871 – 1880	19	1	5
1881 – 1890	16	nil	5
1891 – 1900	12	nil	2
1901 – 1910	16	1	8
1911 – 1920	16	nil	3
1921 – 1930	8	1	2
1931 – 1940	11	nil	5
1941 – 1950	8	nil	3
1951 – 1960	13	3	8
(1961 – 1967)	11	1	3

(See Ed. note preceding references).

of rainfall higher than 3 in/h are used in the design and construction of drains. This would certainly be very costly and might well be uneconomic since many urban areas might go 50 years before drains were tested to capacity by present standards. It is likely, and certainly worthy of investigation on a local scale, that urban topography produces a much higher flood risk in some areas than others, so that higher standards should be adopted where this is the case. The question of whether there has been a recent increase in the frequency of heavy falls of rain in short periods is also worth investigation on a local and a national scale. The causes of such an increase and their possible correlation with other aspects of recent climatic fluctuation might be of some meteorological interest.

Acknowledgements. The authors wish to thank the great number of voluntary observers who have contributed so much of the basic data for this article. They are grateful for assistance provided by the staff of many meteorological offices and the Agriculture and Hydrometeorology Branch (Met. O.8). They particularly wish to thank the Oxford City Engineer and his staff, and the Chief Fire Officers of Oxford and Oxfordshire for their co-operation and for allowing access to official records relating to the occurrence.

(Ed. note: Since this article was prepared for press the authors have pointed out that another daily fall exceeding 2 in has been recorded at the Radcliffe site: a fall of 3·46 in was recorded on 10 July 1968.)

REFERENCES

1. LOWNDES, C. A. S.; The forecasting of rain in southerly airstreams over south-east England in summertime. *Met. Mag., London*, **96**, 1967, p. 212.
2. SMITH, C. G.; Heavy thunderstorm at Oxford. *Weather, London*, **7**, 1952, p. 163.
3. London, Meteorological Office. *British rainfall, 1935*, 1936, p. 262.
4. Report of the City Engineer to the Housing Committee of the Oxford City Council: Storm of 13 July 1967, Blackbird Leys and Minchery Housing Estates, 21 July 1967. Available for inspection on application to the City Engineer, Oxford.
5. London, Meteorological Office. *British rainfall, 1957*, 1960, p. 43 and *1958*, 1963, p. 39.
6. HOWE, G. M., SLAYMAKER, H. O., HARDING, D. M.; Some aspects of the flood hydrology of the upper catchments of the Severn and Wye. *Trans. Inst. Br. Geogr. London*, No. 41, 1967, p. 55.

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TURBULENT HEAT FLUX PATTERNS OVER THE NORTH ATLANTIC DURING SOME RECENT WINTER MONTHS

By A. PERRY, University of Southampton

Summary. The use of ocean weather station data and the turbulent-flux formulae developed by Shellard has made it possible to investigate the patterns of energy transfer over the North Atlantic Ocean and to locate the major influx and efflux regions on the monthly time scale. Anomalous winter circulation patterns (1962/3 – 1964/5) have been linked with anomalies in the positions and intensities of the centres of sensible and latent heat transfer.

Introduction. It is generally recognized that a knowledge of the rates of energy exchange between sea and atmosphere is a fundamental requirement for a proper understanding of the atmospheric circulation. Hare[1] has remarked that the outstanding change in our climatology during post-war years has been the shift away from such parameters as temperature and relative humidity towards the measurement of fluxes. The importance of these studies has been heightened by the findings of Namias [2,3] and Bjerknes,[4] that feedback processes between abnormal sea or land surfaces and the atmosphere may be responsible for climatic anomalies on many time scales. From the work of Budyko,[5] and Jacobs,[6] it is known that the mean distribution of the budget terms and their relative importance varies widely both seasonally and geographically. Gagnon[7] has shown that the radiative terms of the energy budget are relatively constant geographically in comparison with the turbulent-flux terms, although they are of the same order of magnitude. The energy budget is made up of two components; the stable radiative one dependent on climatic variations and latitude, and little influenced by changes in the circulation patterns; and the unstable turbulent flux, where the aperiodic fluctuations caused by the circulation exceed the latitudinal variations.

Since the end of World War II it has become possible to investigate energy transfers over the North Atlantic by using ocean weather station (OWS) records and there is now sufficient data available to make worth while the determination of the average positions and intensities of the main influx and efflux regions.

Method. Shellard[8] has investigated the annual variation of the various terms of the energy budget over the nine-year period 1948–56 at OWS I and J, and his general precedure for calculating the energy used for evaporation Q_e and the sensible heat exchanged between sea and atmosphere Q_h were used in this study. His final formulae are

$$Q_e = 0{\cdot}00547\ (e_w - e_a)\ W_a\ L_t \qquad \ldots (1)$$

where e_w is the vapour pressure at the sea surface, e_a is the vapour pressure at height a, W_a is the wind speed at height a and L_t is the latent heat of vaporization of water at sea temperature g cal/g and is here taken to be $605 - 0{\cdot}29\ t_w$ g cal/g where t_w is the sea surface temperature in °F, and

$$Q_h = 0{\cdot}00199\ (t_w - t_a)\ W_a\ L_t \qquad \ldots (2)$$

where t_w and t_a are the sea and air surface temperatures in °F respectively.

There is little general agreement as to the most reliable and accurate method of calculating the turbulent heat fluxes and it may be that Shellard's

formulae are inaccurate under conditions of high wind speed and extreme instability. The mean values presented by Kraus and Morrison[9] are somewhat higher than those in Table I, perhaps because of the absence of a correction for covariance in the Shellard formulae. The relationship between the energy budget terms and the meteorological elements is generally non-linear and this inherent error is present when using mean values of the meteorological parameters. Nevertheless, there seems little doubt that the results obtained by using the formulae give a first approximation to the distribution of energy input and output over the North Atlantic.

TABLE I—MEAN SENSIBLE AND LATENT HEAT TRANSFER DURING THE WINTERS OF 1951–66

Col. (i) Mean sensible heat flux (cal/cm² per day). Col. (ii) Mean latent heat flux (cal/cm² per day). Col. (iii) Standard Deviation of total flux values. Col. (iv) Highest total heat flux value during the period 1951–66 (cal/cm² per day). Col. (v) Lowest total heat flux value during the period 1951–66 (cal/cm² per day).

OWS A

	(i)	(ii)	(iii)	(iv)	(v)
December	124	202	105	534 (1960)	219 (1963)
January	149	204	113	523 (1951)	225 (1963)
February	102	113	93	542 (1959)	155 (1964)

OWS B

	(i)	(ii)	(iii)	(iv)	(v)
December	179	264	137	702 (1956)	158 (1961)
January	254	282	190	1146 (1957)	226 (1955)
February	197	236	153	762 (1962)	209 (1960)

OWS C

	(i)	(ii)	(iii)	(iv)	(v)
December	81	253	126	583 (1956)	113 (1952)
January	69	225	113	561 (1962)	178 (1956)
February	47	172	102	411 (1959)	36 (1965)

OWS D

	(i)	(ii)	(iii)	(iv)	(v)
December	178	561	86	1161 (1951)	445 (1966)
January	191	576	152	1085 (1964)	471 (1952)
February	219	568	204	1203 (1957)	448 (1956)

OWS E

	(i)	(ii)	(iii)	(iv)	(v)
December	62	440	169	887 (1961)	208 (1956)
January	64	453	148	787 (1966)	237 (1956)
February	71	468	103	691 (1955)	383 (1962, 63)

OWS I

	(i)	(ii)	(iii)	(iv)	(v)
December	141	318	93	582 (1957)	352 (1953)
January	145	300	119	639 (1952)	221 (1964)
February	112	253	88	512 (1957)	255 (1965)

OWS J

	(i)	(ii)	(iii)	(iv)	(v)
December	83	301	90	548 (1958)	277 (1966)
January	87	286	80	449 (1962)	207 (1964)
February	71	255	112	559 (1957)	150 (1952)

OWS K

	(i)	(ii)	(iii)	(iv)	(v)
December	37	249	85	535 (1958)	168 (1953)
January	33	219	96	507 (1963)	103 (1953)
February	42	255	107	501 (1960)	141 (1966)

OWS M

	(i)	(ii)	(iii)	(iv)	(v)
December	139	269	85	616 (1961)	279 (1953)
January	154	272	84	541 (1963)	304 (1952)
February	150	252	96	580 (1962)	210 (1951)

Note. The climatological means on which Table I is based were derived from four publications.[11, 12, 13, 14]

From Table I it can be seen that large intermonthly and interannual variations occur in both sensible and latent heat flux terms. The largest energy transfers normally occur in the south-western North Atlantic in the vicinity of OWS D and OWS E but in some months the zone of maximum energy input can be displaced to other areas. In January 1952, for example, the highest values were in a band extending from OWS B to OWS I. This type of pattern can be expected to have considerable importance for the development and steering of sea level depressions and anticyclones.

In order to examine possible mechanisms affecting the relative variability pattern shown in Figure 1 it was decided to find out whether any correlation existed between the total heat flux values and the zonal index. At OWS C a correlation coefficient of 0·64, significant at the 2 per cent level, was found between the North Atlantic Westerlies circulation intensity index (over-all pressure difference, highest–lowest) (Lamb and Johnson[10]) and the total heat flux values. At no other ocean weather station was there a comparable correlation. The large relative variability at OWS B may be due to fluctuations in the ice limit from year to year affecting the results.

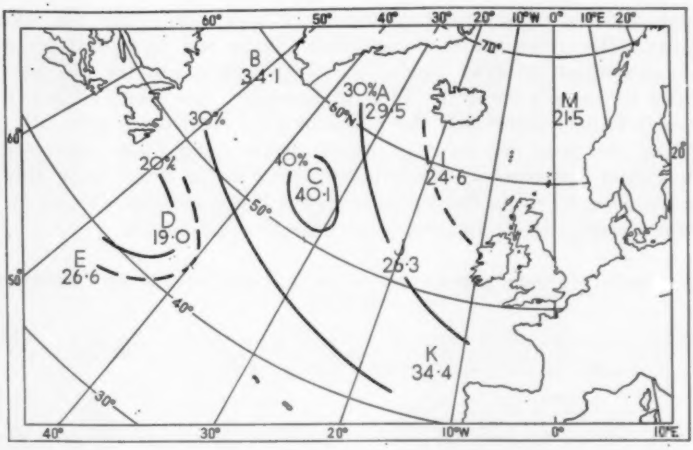

FIGURE 1—MEAN RELATIVE VARIABILITY OF SENSIBLE AND LATENT HEAT OVER THE NORTH ATLANTIC OCEAN, DECEMBER – FEBRUARY

The values shown are percentage variability, and isopleths are at 10 per cent intervals.

Characteristics of the three winters 1962/63, 1963/64 and 1964/65. A notable feature in each of the three winters 1962/63, 1963/64 and 1964/65 was the presence on the mean monthly pressure map, in at least one of the winter months, of an intense anticyclone in the European/east Atlantic sector. In no month since February 1932 has such strong and persistent blocking occurred over the oceanic areas between the British Isles and Greenland as in January 1963 and February 1965. The first winter of the series has already attracted a good deal of attention (Landsberg,[15] Murray[16]) and Murray[17] has commented on the exceptional blocking pattern and the resulting temperature and precipitation anomalies that dominated the large-scale circulation in February 1965.

During the 1963/64 winter, January was the most anomalous month. The mean surface-pressure chart shows a large high covering most of western and central Europe and giving positive anomalies of +15mb at its centre. As in the other two winters there were large temperature and precipitation anomalies in the Atlantic/European sector. It was warmer than normal in a belt extending from western Greenland to Sweden and considerably colder than is usual in a similar east–west belt that stretched from western Europe south-eastwards to the Red Sea. Over the north-east Atlantic southerly advection was very marked. Using the Belasco[18] criteria of air-mass definition there were 16 days during the month at OWS J when maritime tropical air was present at the surface.

Both Namias[19] and Murray[16] have commented on the tendency for months with a high percentage of blocked days over the North Atlantic to be characterized by a sea temperature anomaly pattern which has positive anomalies in high latitudes and negative anomalies in low latitudes. The

following table shows that such a pattern was again operative during the three months January 1963, January 1964 and February 1965.

TABLE II—MEAN SEA TEMPERATURE ANOMALIES FOR JANUARY 1963, JANUARY 1964 AND FEBRUARY 1965

	Ocean Weather Station								
	A	I	J	K	M	B	C	D	E
Anomaly *deg F*	+1·2	+0·1	+0·1	−0·1	+0·7	+1·0	+0·8	−0·5	−1·4

(Based on normals for the period 1931–60 published by the World Meteorological Organization, WMO/OMM No. 117, TP52, Geneva, 1962.)

While it would seem logical to suppose that higher sea temperatures than normal at the northern ocean weather stations would lead to an increase of air–sea temperature difference and air–sea vapour pressure difference and thus increase the energy transfer to the atmosphere, this may not be true under certain circulation conditions. The southerly advection of mild moist maritime tropical air, usually with a negative air–sea temperature difference over the north-east Atlantic, is a feature of blocking spells when the blocking high is situated over north-west Europe. With these conditions a warmer than normal ocean has the effect of widening the air–sea temperature difference and of increasing the downward flux of energy. In addition, Hay[20] has shown that at OWS J, after a period of successive days with anticyclonic conditions in winter, the air temperature rises much more rapidly than the sea temperature so that the air–sea temperature difference is progressively reduced. There seems little reason why this process should not be operative at other stations as well.

Turbulent heat flux patterns during the three winters. It was considered likely that the extremely anomalous atmospheric circulations during the three winters would be reflected in the position and intensities of the main heat-exchange maxima and minima compared with the normal. Accordingly the sensible and latent heat budgets were calculated for the three months December – February during each winter at the nine ocean weather stations in the North Atlantic. Space allows the reproduction of only three of the maps obtained. Each map has been coupled with one showing depression tracks during the month.

(i) *January* 1963. (Figures 2*a* and 2*b*). The lowest turbulent-flux values over the North Atlantic were recorded at OWS A where there was a value of only 225 cal/cm^2 per day. The low mean wind speed and the stable atmosphere associated with the blocking high which dominated the North Atlantic during the month can be held to account for the low values. Figure 2*a* shows a large zone of maximum transfer extending probably from the North American coast along the north edge of the Gulf Stream drift. This zone is seen to be a major birthplace for depressions which subsequently moved eastward across the North Atlantic south of 50°N. The large number of days of cold air advection from Europe over the eastern Atlantic resulted in a band of high turbulent-flux values off the west European coast. At OWS K continental air masses gave unusually large air–sea temperature differences and air–sea vapour pressure differences, which resulted in a positive anomaly of +250 cal/cm^2 per day compared with the calculated mean January values.

FIGURE 2*a*—TURBULENT FLUXES OVER THE NORTH ATLANTIC OCEAN, JANUARY 1963

Isopleths are at intervals of 100 cal/cm² per day.

FIGURE 2*b*—DEPRESSION TRACKS OVER THE NORTH ATLANTIC OCEAN, JANUARY 1963

The direction of movement is shown by an arrow and the position of a depression at 1200 GMT is indicated by a closed circle.

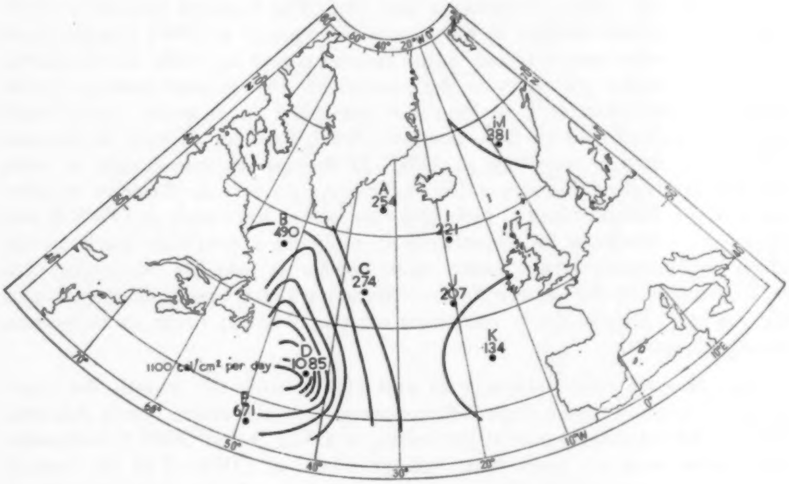

FIGURE 3*a*—TURBULENT FLUXES OVER THE NORTH ATLANTIC OCEAN, JANUARY 1964

Isopleths are at intervals of 100 cal/cm² per day.

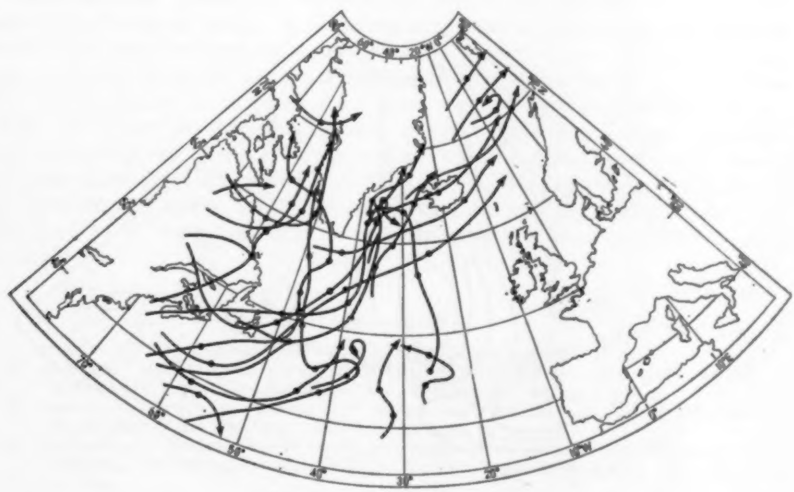

FIGURE 3*b*—DEPRESSION TRACKS OVER THE NORTH ATLANTIC OCEAN, JANUARY 1964

The direction of movement is shown by an arrow and the position of a depression at 1200 GMT is indicated by a closed circle.

(ii) *January* 1964. (Figures 3*a* and 3*b*). The frequent advection of air from low latitudes resulted in the air–sea interchange at OWS I being lower than in any other winter month in the 16-year period 1951–66. The Icelandic low was displaced 300 miles to the south-west of its normal position on the mean monthly chart with its long axis orientated north–south. As a result, repeated spells of cold air from northern North America affected the western Atlantic in such a way that at OWS D the air–sea interchange in 1964 reached the highest January value of the 1951–66 period. Relative to other parts of the North Atlantic, turbulent-flux values were high at OWS B and there was a tendency for depressions to move on a northerly track up the Davis or Denmark Straits rather than north-east into the Norwegian Sea as is normal. On the eastern flanks of these lows severe gales developed, and the *Mariners' Weather Log*[21] comments on the delay to liners in mid-ocean during the month.

(iii) *February* 1965. (Figures 4*a* and 4*b*). During this month the input of energy seems to have been below normal over the entire North Atlantic. Even in the south-west part of the ocean, at OWS D and OWS E turbulent-flux values were no more than average whilst at OWS C in the central Atlantic there was the lowest air–sea energy exchange in any January between 1951–66. At this ocean weather station the sensible heat budget was negative, a feature which is normally restricted to the summer months. Cyclonic activity was everywhere considerably below normal (Figure 4*b*). Depressions in the west Atlantic turned north up the Davis Strait or progressed eastward in low latitudes. Figure 4*a* clearly shows the corresponding tongue of relatively high air–sea energy input extending from the west Atlantic to Spain.

FIGURE 4*a*—TURBULENT FLUXES OVER THE NORTH ATLANTIC OCEAN, FEBRUARY 1965

Isopleths are at intervals of 100 cal/cm² per day.

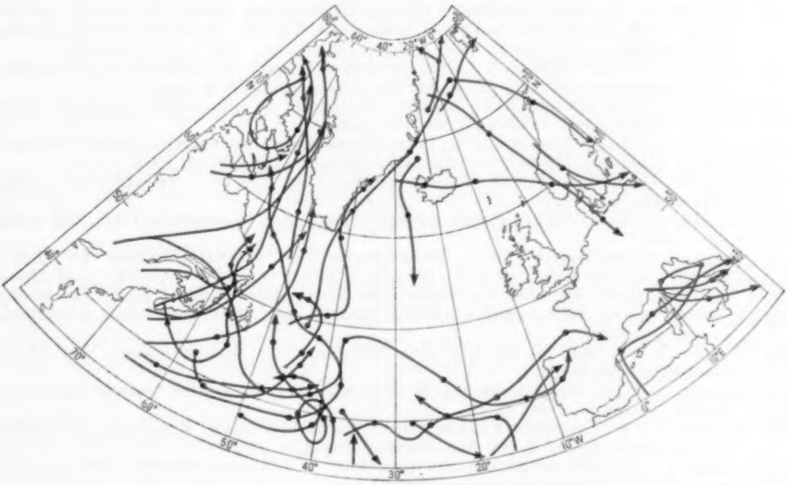

FIGURE 4*b*—DEPRESSION TRACKS OVER THE NORTH ATLANTIC OCEAN, FEBRUARY 1965

The direction of movement is shown by an arrow and the position of a depression at 1200 GMT is indicated by a closed circle.

Conclusions. Since both sensible and latent heat transfer are related to wind speed and air mass it is to be expected that a synchronous relationship will exist between synoptic and turbulent transfer maps. It appears that the exchange formulae are on a sufficiently sound footing to enable useful flux-computations to be made from easily obtainable ocean weather station data. However, an extensive analysis of the various heat-budget equations in use is required in order to determine which is the most suitable under varying conditions of stability and wind speed. The catalogue, in Table I, of sensible and latent heat fluxes in winter, extends some of the results of Shellard to a larger area and to a more-extended, overlapping, period of record.

REFERENCES

1. HARE, F. K.; The concept of climate. *Geography, London*, **51**, 1966, p. 99.
2. NAMIAS, J.; Recent seasonal interactions between North Pacific waters and the overlying atmospheric circulation. *Jnl geophys. Res., Richmond, Va.*, **64**, 1959, p. 631.
3. NAMIAS, J.; Feed-back influences of surface abnormalities on short period climatic fluctuations. *Aust. Met. Mag., Melbourne*, **37**, 1962, p. 47.
4. BJERKNES, J.; Synoptic survey of the interaction of sea and atmosphere in the North Atlantic. *Geophysica Norvegica* (Vilhelm Bjerknes 100th anniversary), *Oslo*, **24**, 1962, p. 115.
5. BUDYKO, M. I.; Atlas of heat balance, Second edition. Leningrad, 1963, p. 69. (English translation McGill Univ., Montreal).
6. JACOBS, W. C.; The energy exchange between sea and atmosphere and some of its consequences. *Bull. Scripps Instn Oceanogr., La Jolla, Cal.*, **6**, 1951, p. 27.
7. GAGNON, R. M.; Types of winter energy budgets over the Norwegian Sea. Montreal, Arctic Meteorology Research Group, Publication in Meteorology No. 64, McGill Univ., Montreal, 1964, p. 56.

8. SHELLARD, H. C.; Some calculations of terms in the energy balance for monthly periods at the ocean weather stations I and J in the North Atlantic. *Scient. Pap. met. Off., London*, No. 11, 1962, p. 13.
9. KRAUS, E. B. and MORRISON, R. E.; Local interactions between the sea and the air at monthly and annual time scales. *Q. Jnl R. met. Soc., London*, **92**, 1966, p. 114.
10. LAMB, H. H. and JOHNSON, A. I.; Secular variations of the atmospheric circulation since 1750. *Geophys. Mem., London*, **14**, No. 110, 1966.
11. PFLUGBEIL, C. and STEINBORN, E.; Zur Klimatologie des Nordatlantischen Ozeans. Teil 2. Hamburg, Deutscher Wetterdienst, Seewetteramt, Nr. 39, 1963.
12. Asheville, U.S. Department of Commerce. *Mon. Clim. Data Wld.* Asheville, Vol. 14–20, 1961–1966.
13. Washington, U.S. Weather Bureau. *Mariners' Weather Log.* Washington D.C., Vol. 5–10, 1961–1966.
14. London, Meteorological Office. Meteorological and Current Summary for Ocean Weather Stations India (59°00′N, 19°00′W.), Juliett (52°30′N. 20°00′W.), and Alpha (62°00′N. 33°00′W.). (Copy available in the Meteorological Office Library, Bracknell.)
15. LANDSBERG, H. E.; The unusual weather of January 1963. *Mon. Weath. Rev., Washington*, **91**, 1963, p. 307.
16. MURRAY, R.; A note on the large-scale features of the 1962/63 winter. *Met. Mag., London*, **95**, 1966, p. 339.
17. MURRAY, R.; The blocking pattern of February 1965 and a good pressure analogue. *Weather, London*, **21**, 1966, p. 66.
18. BELASCO, J. E.; Temperature characteristics of different classes of air over the British Isles in winter. *Q. Jnl R. met. Soc., London*, **71**, 1945, p. 351.
19. NAMIAS, J.; Seasonal persistence and recurrence of European blocking during 1958–1960. *Tellus, Stockholm*, **3**, 1964, p. 394.
20. HAY, R. F. M.; Some aspects of variations of air and sea surface temperatures in short periods at ocean weather stations I and J of significance to the synoptic climatologist. *Met. Res. Pap., London*, No. 949, 1956. (Available in the Meteorological Office Library, Bracknell).
21. Washington, U.S. Weather Bureau. *Mariners' Weather Log* Washington D.C., 1964, p 120.

NOTES AND NEWS

Address by Sir Joseph Hutchinson, C.M.G., Sc.D., F.R.S.

At various times interesting personalities distinguished in subjects related to meteorology have been invited by the Director-General to visit Bracknell and address an audience of meteorologists and other scientists. On 21 May 1968 a lecture in this series was given by Sir Joseph Hutchinson, C.M.G., Sc.D., F.R.S., Drapers' Professor of Agriculture, Cambridge, at the South-East Berkshire College of Further Education, the subject being 'The Improvement of Agricultural Production'.

Sir Joseph traced the history of agriculture from its earliest days, showing how man progressed from the wasteful shifting-cultivation processes to modern production on land where high fertility was consciously maintained. Touching upon the constant leap-frogging between food yields and consumer demand he pointed out that it had taken approximately 5000 years for the farmer to increase his production (of cereals) per acre by a factor of 30, largely due to the 'fertilizer revolution' of recent years.

He stressed that the urgent need of today was to ensure that the developing nations make similar progress in a far shorter time, and maintained that correct soil fertilization was the most important factor in that it lay within the power of science and husbandry to control it. He illustrated the various types of problem that arise by a series of slides of crops in Uganda, the Sudan and Colombia.

Perhaps wisely, he did not take into detailed account the climatic limitations on agricultural production, but in answer to a question as to why Japan had been so successful in post-war years, he replied 'Hard work', thus drawing attention to the most intractable factor of all — man himself.

It is perhaps no coincidence that the most striking improvements in agricultural production have been made in areas which contain the least adverse climatic factors, the highest degree of scientific intelligence and the undeniable presence of that indefinable parameter — the will to work.

In thanking Sir Joseph, the Director-General said that this had been one of the most interesting lectures of the series. It is indeed a pleasure and a privilege to listen to a good speaker dealing with a subject, near to his heart, in which he is a self-evident expert.

L. P. SMITH

HONOUR

The following award to a member of the Meteorological Office was announced in the Queen's Birthday Honours List, 1968 :

B.E.M.

P. A. Warn, Senior Scientific Assistant, Bracknell.

CORRIGENDA

Meteorological Magazine, June 1968, p. 165.
Figure 1, Honington should be at 52° 20′N. 0° 47′E., i.e. north of the position shown and almost east of Mildenhall.

Meteorological Magazine, June 1968, pp. 185 and 186.
In changing from $\log_e$ to $\log_{10}$ a factor was inadvertently omitted and the lag times given in the last paragraph should be divided by 2·3. The following are the details of changes required :

p. 185 the equation should read :

$$\log_e(T - T_A) + \text{constant} = -t/L;$$

p. 186 lines 5 and 8 : for 'L' read '$2{\cdot}3L$';
line 10 : the expression should read $L \simeq 8{\cdot}2/(v)^{\frac{1}{2}}$
and line 13 should read $L \simeq 5{\cdot}2/(v)^{\frac{1}{2}}$;
In Figure 3 : for $\log_{10}L$ read $\log_{10} 2{\cdot}3L$;
in the last paragraph, for '30 to 6·5 minutes' read '13 to 2·8 minutes' and for '15·3 to 6 minutes' read '6·6 to 2·6 minutes'.


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